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INTERNATIONAL PATENT APPLICATION PCT/EP03/00596
OUR REF : CR00548P C01/MAW
In response to the Written Opinion of 17th October 2003

Dear Sirs

With reference to the **Written Opinion of 17th October 2003** and the communication of 23rd January 2004 extending the time limit for reply, the .Applicant wishes to amend the claims of the application, with consequential amendments to the introduction, and herewith files new pages 3 to 5 and 17 to 22 to replace the corresponding pages 3 to 5 and 17 to 32 of the specification as filed, together with copies of the pages identifying the amendments made. In view of the extensive revision to the claims, the original claim numbering has been maintained in the copy identifying the amendments made, claim 22 having been renumbered as claim 1 in the new pages.

We believe that all the Examiner's objections have been met and allowance of the present application is respectfully requested. However, in the event that any other questions arise, the Examiner is invited to call the undersigned at +33 1 69 35 25 74.

The Applicant hereby authorises that in this application any fees and costs falling due be automatically debited from Deposit Account No. 28050071.

Martin WHARMBY
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for multiple antennas systems in the publication by G.J. Foschini and M.J. Gans, "On Limits of Wireless Communications in a fading Environment when Using Multiple Antennas", *Wireless Personnal Communications* 6:311-335, 1998. However, it has been demonstrated (in the publication by P. Loubaton, M. Debbah and M. de Courville, "Spread OFDM Performance with MMSE Equalization", in *International Conference on Acoustics, Speech, and Signal Processing*, Salt Lake City, USA, May 2001) that V-BLAST algorithms are not suited for conventional SOFDM systems due to the averaging of the SNRs (signal/noise ratios) at the receiver across the carriers during the despreading step. Moreover, such approaches lead to a tremendous decoding complexity due to the computation of several pseudo inverse matrices.

A need therefore exists for an OFDM communication system and decoding algorithm for use therein wherein the abovementioned disadvantage(s) may be alleviated.

Statement of Invention

~~In accordance with a first aspect of the present invention there is provided a spread OFDM wireless communication system as claimed in claim 1.~~

~~In accordance with a second aspect of the present invention there is provided a spread OFDM wireless communication system as claimed in claim 10.~~

~~In accordance with a third aspect of the present invention there is provided a receiver, for use in a spread OFDM wireless communication system, as claimed in claim 11.~~

~~In accordance with a fourth aspect of the present invention there is provided a receiver, for use in a spread OFDM wireless communication system, as claimed in claim 18.~~

~~In accordance with a fifth aspect of the present invention there is provided~~ The present invention provides a method of decoding a received spread OFDM wireless communication signal, ~~of operating~~and a receiver comprising decoding means for decoding a received signal by such a method, in a spread OFDM wireless communication receiver, as described in the accompanying ~~claimed in~~ claims~~ 19~~.

~~In accordance with a sixth aspect of the present invention there is provided a method, for performing minimum mean square error equalization in a spread OFDM wireless communication system, as claimed in claim 27.~~

~~In one aspect, the present invention provides a new, efficient yet simple, low complexity decoding algorithm for an enhanced OFDM modulator.~~

~~Preferably the OFDM modulator is based on a Walsh-Hadamard transform, allowing exploitation of the mathematical properties of a Walsh-Hadamard precoder.~~

In one ~~form~~ embodiment of the present invention, the ~~new~~ decoding algorithm ~~consists in~~ comprises splitting a received block into two equal parts, one of the parts being decoded first and then subtracted from the received vector to suppress part of the interference and the other of the parts being decoded next. This iterative procedure can be further extended by successive block splitting and results in a multi-resolution decoding algorithm. An attractive property of this algorithm is that although it still relies on the computation of pseudo-inverses, the expressions of these pseudo-inverses are easy to derive and may consist simply in the product of a diagonal matrix by a Walsh Hadamard transform. Thus, using Walsh Hadamard spreading sequences, the inherent complexity penalty of a V-BLAST decoding schemes is simply removed. This allows a significant gain in performance (e.g., around 3-4dB compared to MMSE SOFDM) with only a modest increase in complexity, which motivates:

i) the use of such new modulation schemes in practice and

ii) their proposal as a solution for future wireless LAN standards.

The following technical merits of the ~~new~~ multi-resolution decoding algorithm of this embodiment of the present invention can be highlighted:

- Low arithmetical complexity compared to existing SIC BLAST techniques with same or better performance.
- Flexibility and scalability of the method (it is possible to adjust the number of iterations to be

performed based on a performance/complexity tradeoff).

- Can be combined into all OFDM standards as a proprietary transmission mode (since it can be

Claims

~~1. A spread OFDM wireless communication system (100) comprising:~~

~~at a transmitter (110-140)~~

~~means for transmitting a spread OFDM signal;~~

~~at a receiver (160-180)~~

~~means for receiving the spread OFDM signal;~~

~~means for equalizing the spread OFDM signal~~

~~means for splitting the equalized spread OFDM signal into a first plurality of portions including a first portion and a second portion;~~

~~means for making a decision on the second portion to produce a decided second portion;~~

~~means for subtracting the decided second portion from the received spread OFDM signal to produce a first difference signal; and~~

~~means for equalising and processing the first difference signal to recover the first portion of the received signal in which interference due to second portion interfering terms is substantially reduced.~~

~~2. The system of claim 1 further comprising:~~

~~at the receiver (160-180)~~

~~means for making a decision on the first portion to produce a decided first portion;~~

~~means for subtracting the first portion from the equalised spread OFDM signal to produce a second difference signal; and~~

~~means for equalising and processing the second difference signal to recover the second portion of the received signal in which interference due to first portion interfering terms is substantially reduced.~~

~~3. The system of claim 2 wherein the receiver (160-180) further comprises means for repeating processing a predetermined number of further times, with the recovered first and second portions in place of the decided first and second portions, to recover more reliable estimates for the first and second portions.~~

~~4. The system of claim 1, 2 or 3 further comprising:~~

~~at the receiver (160-180)~~

~~means for splitting the recovered received signal into a second plurality of portions greater in number than the first plurality of portions and including a first subsequent portion, a second subsequent portion, a third portion and a fourth portion;~~

~~means for subtracting the second subsequent portion, the third portion and the fourth portion from the received signal to produce a first subsequent difference signal; and~~

~~means for processing the first subsequent difference signal to recover the first subsequent portion of the recovered received signal in which interference due to second, third and fourth portion interfering terms is substantially reduced;~~

~~means for making a decision on the first subsequent portion to produce a decided first subsequent portion;~~

~~means for subtracting the first subsequent portion, the third portion and the fourth portion from the received signal to produce a second subsequent difference signal; and~~

~~means for processing the second subsequent difference signal to recover the second subsequent portion of the recovered received signal in which interference due to first, third and fourth portion interfering terms is substantially reduced;~~

~~means for making a decision on the second subsequent portion to produce a decided second subsequent portion;~~

~~means for subtracting the first subsequent portion, the second subsequent portion and the fourth portion from the received signal to produce a third difference signal;~~

~~means for processing the third difference signal to recover the third portion of the recovered received signal in which interference due to first, second and fourth portion interfering terms is substantially reduced;~~

~~means for making a decision on the third portion to produce a decided third portion;~~

~~means for subtracting the first subsequent portion, the second subsequent portion and the third portion from the received signal to produce a fourth difference signal;~~

~~means for processing the fourth difference signal to recover the fourth portion of the recovered received signal in which interference due to first, second and third portion interfering terms is substantially reduced; and~~

~~means for making a decision on the fourth portion to produce a decided fourth portion.~~

~~5. The system of claim 4 wherein the receiver (160-180) further comprises means for repeating processing a predetermined number of further times, with the decided first subsequent portion, the decided second subsequent portion, the decided third portion and the decided fourth portion in place of the recovered first subsequent portion, the recovered second subsequent portion, the recovered third portion and the recovered fourth portion respectively, to recover more reliable estimates for the first subsequent portion, the second subsequent portion, the third portion and the fourth portion.~~

~~6. The system of claim 4 wherein the second plurality of portions is an integer multiple of 2 that is greater than 2.~~

~~7. The system of any preceding claim wherein the means for equalising and processing comprises:~~

~~first matrix multiplication means for multiplying by a first diagonal matrix having elements dependent on channel coefficients; and~~

~~second matrix multiplication means for multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.~~

~~8. The system of any preceding claim wherein the means for equalising and processing comprises means for performing minimum mean square error equalization.~~

~~9. The system of any preceding claim wherein the means for transmitting a spread OFDM signal comprises means for spreading by performing a Walsh Hadamard transform.~~

~~10. A spread OFDM wireless communication system (100) comprising:~~

~~at a transmitter (110-140)~~

~~means for transmitting a spread OFDM signal;~~

~~at a receiver (160-180)~~

~~means for performing minimum mean square error equalization having:~~

~~first matrix multiplication means for multiplying by a first diagonal matrix having elements dependent on channel coefficients; and~~

~~second matrix multiplication means for multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.~~

11. A receiver (160-180) for use in a spread OFDM wireless communication system (100), the receiver comprising~~:~~

means for receiving a ~~wireless~~ spread OFDM wireless communication signal, and decoding means for decoding the received signal by a method as claimed in any of claims 20 to 25, said decoding means comprising~~;~~:

equalizing and decision means for performing said equalizing and decision function on the received spread OFDM signal (y),

means for splitting the equalized and decided spread OFDM signal block ($\hat{s}$) into a number 2^i ~~first plurality~~ of portions ($\hat{s}_1$, $\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$), where i is positive integer~~including a first portion and a second portion~~;

characterised by:

~~means for making a decision on the second portion to produce a decided second portion;~~

subtracting means for subtracting, for each of said portions ($\hat{s}_1$) of the equalized and decided signal block in turn, said values ($M\begin{bmatrix}0\\ \hat{s}_2\\ \hat{s}_3\\ \hat{s}_4\end{bmatrix}$) derived from the decided ~~second~~ other portions ($\hat{s}_2$ to $\hat{s}_4$) of the equalized and decided signal block from the received ~~spread OFDM~~ signal block (y) to produce a ~~first~~ respective difference signal;~~and~~

said equalizing and decision means being arranged to perform said ~~means for~~ equalising and decision function on ~~processing~~ the ~~first~~ respective difference signal to produce said further processed equalized and decided ~~recover the first~~ portion ($\hat{\hat{s}}_1$) of the received signal in which ~~of~~ interference due to ~~second~~ the other portions ($\hat{s}_2$ to $\hat{s}_4$) of the equalized and decided signal block ~~interfering terms~~ is substantially reduced;

and said decoding means being arranged to repeat, for each of the other portions ($\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$) of the signal block, said steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed equalized and decided portion.

12. ~~The~~ A receiver ~~of~~ as claimed in claim 11 ~~further comprising:~~

~~means for making a decision on the first portion to produce a decided first portion;~~

wherein said subtracting means ~~for~~ is arranged so that repeating subtracting the ~~first~~ values derived from the other portions of ~~from~~ the equalised ~~spread OFDM~~and decided signal block from the received signal to produce a ~~second~~ respective further difference signal~~; and~~

~~means for equalising and processing the second difference signal to recover the second portion of the received signal in which interference due to first portion interfering terms is substantiallyreduced~~ comprises subtracting values derived from at least one of said further processed portions ($\hat{\hat{s}}_2$ to $\hat{\hat{s}}_4$) of the received signal from the received spread OFDM signal (y).

13. ~~The~~ A receiver ~~of~~ as claimed in claim 11 or 12 wherein ~~the receiver further comprises~~said decoding means ~~for repeating~~ is arranged to iterate processing the signal block, including iterating the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed equalized and decided portion with values derived from the further processed ~~a predetermined number of further times, with the recovered first and second~~ portions ($\hat{\hat{s}}_1$ to $\hat{\hat{s}}_4$) in place of ~~the decided first and second~~ previously processed portions ($\hat{\hat{s}}_1$ to $\hat{\hat{s}}_4$), to recover still more reliable estimates for each of the ~~first and second~~ portions.

~~14. The receiver of claim 11, 12 or 13 further comprising:~~

~~means for splitting the recovered received signal into a second plurality of portions greater in number than the first plurality of portions and including a first~~

~~subsequent portion and a second subsequent portion, a third portion and a fourth portion;~~

~~means for subtracting the second subsequent portion, the third portion and the fourth portion from the recovered received signal to produce a first subsequent difference signal; and~~

~~means for processing the first subsequent difference signal to recover the first subsequent portion of the recovered received signal in which interference due to second, third and fourth portion interfering terms is substantially reduced;~~

~~means for making a decision on the first subsequent portion to produce a decided first subsequent portion;~~

~~means for subtracting the first subsequent portion, the third portion and the fourth portion from the received signal to produce a second subsequent difference signal;~~

~~means for processing the second subsequent difference signal to recover the second subsequent portion of the recovered received signal in which interference due to first, third and fourth portion interfering terms is substantially reduced;~~

~~means for making a decision on the second subsequent portion to produce a decided second subsequent portion;~~

~~means for subtracting the first subsequent portion, the second subsequent portion and the~~

~~fourth portion from the received signal to produce a third difference signal;~~

~~means for processing the third difference signal to recover the third portion of the recovered received signal in which interference due to first, second and fourth portion interfering terms is substantially reduced;~~

~~means for making a decision on the third portion to produce a decided third portion;~~

~~means for subtracting the first subsequent portion, the second subsequent portion and the third portion from the received signal to produce a fourth difference signal;~~

~~means for processing the fourth difference signal to recover the fourth portion of the recovered received signal in which interference due to first, second and third portion interfering terms is substantially reduced; and~~

~~means for making a decision on the fourth portion to produce a decided fourth portion.~~

15. ~~The~~ A receiver ~~of~~ as claimed in claim 13~~4~~ wherein said decoding means is arranged so that iterating processing the signal block includes splitting the equalized and decided spread OFDM signal block ($\hat{s}$) into a number 2^j of portions ($\hat{s}_1$ to $\hat{s}_4$), where j is positive integer greater than i so that iterating the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed portion is performed with a greater number of portions than the previous steps.~~further~~

~~comprising means for repeating processing a predetermined number of further times, with the decided first subsequent portion, the decided second subsequent portion, the decided third portion and the decided fourth portion in place of the recovered first subsequent portion, the recovered second subsequent portion, the recovered third portion and the recovered fourth portion respectively, to recover more reliable estimates for the first subsequent portion, the second subsequent portion, the third portion and the fourth portion.~~

16. ~~The~~ A receiver ~~of~~ as claimed in any ~~one~~ of claims 11~~-~~ to 15 wherein ~~the~~ said equalizing and decision means ~~for equalising and processing~~ comprises~~:~~

~~first~~ matrix multiplication means for multiplying by a first diagonal matrix having elements dependent on channel coefficients~~;~~ and

~~second matrix multiplication means for multiplying~~ by a second matrix which is a subset of a Walsh Hadamard matrix.

17. ~~The~~ A receiver ~~of~~ as claimed in any ~~one~~ of claims 11~~-~~ to 16 wherein ~~the~~ said equalizing and decision means ~~for equalising and processing~~ comprises means for performing minimum mean square error equalization.

~~18. A receiver (160-180) for use in a spread OFDM wireless communication system, the receiver comprising:~~

~~means for performing minimum mean square error equalization having:~~

~~first matrix multiplication means for multiplying by a first diagonal matrix having elements dependent on channel coefficients; and~~

~~second matrix multiplication means for multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.~~

~~19. A method of operating a receiver (160-180) in a spread OFDM wireless communication system (100), the method comprising:~~

~~receiving a wireless spread OFDM signal;~~

~~equalizing the spread OFDM signal~~

~~splitting the equalized spread OFDM signal into a first plurality of portions including a first portion and a second portion;~~

~~making a decision on the second portion to produce a decided second portion;~~

~~subtracting the decided second portion from the received spread OFDM signal to produce a first difference signal; and~~

~~equalising and processing the first difference signal to recover the first portion of the received signal in which of interference due to second portion interfering terms is substantiallyreduced.~~

20. ~~The~~ A method ~~of~~ as claimed in claim ~~19~~ 22 wherein ~~further comprising:~~

~~making a decision on the first portion to produce a decided first portion;~~

repeating subtracting the ~~first~~ values derived from other portions of the equalized and decided signal block from the received ~~equalised spread OFDM~~ signal to produce a ~~second~~ respective further difference signal~~;~~ ~~and~~

~~equalising and processing the second difference signal to recover the second portion of the~~

~~received signal in which interference due to first portion interfering terms is substantiallyreduced~~ comprises subtracting values derived from at least one of said further processed portions ($\hat{\hat{s}}_2$ to $\hat{\hat{s}}_4$) of the received signal from the received spread OFDM signal (y).

21. ~~The~~ A method ~~of~~ as claimed in claim 22 or 20 further comprising iterating processing the signal block, including iterating the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed equalized and decided portion~~repeating processing a predetermined number of further times,~~ with values derived from the ~~recovered~~ further processed ~~first and second~~ portions ($\hat{\hat{s}}_1$ to $\hat{\hat{s}}_4$) in place of ~~the decided~~ previously processed ~~first and second~~ portions ($\hat{s}_1$ to $\hat{s}_4$), to recover still more reliable estimates for each of the ~~first and second~~ portions.

22. ~~The~~ A ~~method of~~comprising~~claim 19, 20 or 21 further comprising~~:

performing an equalizing and decision function on the received spread OFDM signal (y), splitting the equalized and decided spread OFDM ~~recovered received~~ signal block ($\hat{s}$) into a ~~second plurality of portions greater in~~ number 2^i of ~~than the first plurality of portions and~~

~~including a first subsequent~~ portions ($\hat{s}_1$, $\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$) ~~and a second subsequent portion, a third portion and a fourth portion~~, where i is positive integer;

characterised by:

for each of said portions ($\hat{s}_1$) of the equalized and decided signal block in turn subtracting values ($M\begin{bmatrix}0\\ \hat{s}_2\\ \hat{s}_3\\ \hat{s}_4\end{bmatrix}$) derived from the ~~second~~ other ~~subsequent~~ portions ($\hat{s}_2$ to $\hat{s}_4$) of the equalized and decided signal block~~, the third portion and the fourth portion~~ from the ~~recovered~~ received signal block (y) to produce a ~~first~~ respective ~~subsequent~~ difference signal; and

~~processing~~ performing an equalising and decision function on the ~~first~~ respective ~~subsequent~~ difference signal to ~~recover the first subsequent~~ produce a further processed equalized and decided portion ($\hat{\hat{s}}_1$) of the ~~recovered~~ received signal in which interference due to the other ~~second, third and fourth portion interfering term~~portions ($\hat{s}_2$ to $\hat{s}_4$) of the equalized and decided signal block is substantiallyreduced;

~~making a decision on the first subsequent portion to produce a decided first subsequent portion;~~

the steps of producing the ~~subtracting the first subsequent portion, the third portion and the fourth portion from the received signal to produce a second subsequent~~ respective difference signal and performing the equalising and decision function to produce the further processed equalized and decided portion being repeated for each of the other portions ($\hat{s}_2$, $\hat{s}_3$, $\hat{s}_4$) of the signal block.~~;~~

~~processing the second subsequent difference signal to recover the second subsequent portion of the recovered received signal in which interference due to first, third and fourth portion interfering terms is substantially reduced;~~

~~making a decision on the second subsequent portion to produce a decided second subsequent portion;~~

~~subtracting the first subsequent portion, the second subsequent portion and the fourth portion from the received signal to produce a third difference signal;~~

~~processing the third difference signal to recover the third portion of the recovered received signal in which interference due to first, second and fourth portion interfering terms is substantially reduced;~~

~~means for making a decision on the third portion to produce a decided third portion;~~

~~means for subtracting the first subsequent portion, the second subsequent portion and the third portion from the received signal to produce a fourth difference signal;~~

~~processing the fourth difference signal to recover the fourth portion of the recovered received signal in which interference due to first, second and third portion interfering terms is substantially reduced; and~~

~~making a decision on the fourth portion to produce a decided fourth portion.~~

23. ~~The~~ A method ~~of~~ as claimed in claim 21~~2~~ ~~further comprising repeating~~ wherein iterating processing the signal block includes splitting the equalized and decided spread OFDM signal block ($\hat{s}$) into a number 2^j of portions ($\hat{s}_1$ to $\hat{s}_4$), where j is positive integer greater than i so that iterating the steps of producing the respective difference signal and performing the equalising and decision function to produce the further processed portion is performed with a greater number of portions than the previous steps.~~a predetermined number of further times, with the decided first subsequent portion, the decided second subsequent portion, the decided third portion and the decided fourth portion in place of the recovered first subsequent portion, the recovered second subsequent portion, the recovered third portion and the recovered fourth portion respectively, to recover more reliable estimates for the first subsequent portion, the second subsequent portion, the third portion and the fourth portion.~~

~~24. The method of claim 22 wherein the second plurality of portions is an integer multiple of 2 that is greater than 2.~~

25. ~~The~~ A method ~~of~~ as claimed in any ~~one~~ of claims 19~~-~~ to 24 ~~comprising:~~
wherein said equalizing steps comprise multiplying by a first diagonal matrix having elements dependent on channel coefficients; and

multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.

26. ~~The~~ A method as claimed in ~~of~~ any ~~one~~ of claims 19 to ~~-~~25 wherein said equalizing steps comprise~~ing~~ performing minimum mean square error equalization.

~~27. A method for performing minimum mean square error equalization in a spread OFDM wireless communication system (100), the method comprising:~~

~~multiplying by a first diagonal matrix having elements dependent on channel coefficients; and~~

~~multiplying by a second matrix which is a subset of a Walsh Hadamard matrix.~~